PE4.65 Determination of the temperature gradient and cooking loss during microwave heating of beef roasts using a domestic oven 234.00

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Abstract— The purpose of this work was to analyse the heterogeneity of time-temperature kinetics inside two types of muscles during a controlled microwave cooking experiment on calibrated beef roast and its connection with cooking losses. Beef roast were obtained from Semimembranosus (SM) and Semitendinosus (ST) muscles from 8 Friesian yearling heifers and 8 Friesian mature cows. Four treatments using combinations of power (250 vs. 900W) and final meat temperature (60 vs. 80°C) were applied in a 2x2 factorial design. Results showed significant temperature gradients especially along the vertical cross section of the roasts. Temperature variations and time of treatment during heating were higher for SM muscle with larger dimensions compared with ST muscle. Higher power (900W) resulted in higher heating rate and shorter heating times compared with low power (250W). Muscles from cows showed higher heating rate and shorter treatment time compared with heifers. Cooking loss was higher at 80 compared with 60°C with limited effect of power on this parameter. Opposite results in cooking loss were obtained for SM and ST from cows and heifers. Microwave cooking of small roasts inside a domestic oven is heterogeneous leading to under and over-cooked areas. Classical thermocouples used in most studies on cooked meat to monitor temperature and control treatments are not accurate for microwave cooking since fibre probes are difficult to position inside raw meat and sensor location is moving during heating. For microwave heating of meat roasts temperature gradients shall be taken into account in the discussion of observed quality variations.

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***Index Terms*— beef, cooking loss, microwave, time-temperature kinetics**

I. INTRODUCTION

NOWADAYS, microwave cooking has become popular because of its rapid speed of food preparation and amount of energy saved in homes, food processing, and food service operations. Three main factors differ among the various cooking techniques: the temperature on the surface of the meat, the temperature profile through the meat and the method of heat transfer [*1*, *2*].

Cooking losses are mainly due to water and fat reduction during cooking [*3*]. These losses depend on the mass transfer process during thermal treatment [*4*], which in turn is influenced by the characteristics of the cooking procedure (i.e. heating rate, final cooking temperature, etc.) and of the meat matrix (i.e. moisture, fat, and protein composition and size, shape, pH, degree of structural disintegration, etc.) [*3*].

Several studies reported higher cooking losses and consequently lower tenderness or juiciness after heating meat products in a MW oven, in comparison to conventional heating, while others have found no significant differences in these properties. The aim of this work was to evaluate the heterogeneity of time-temperature kinetics inside two types of muscles during a controlled microwave cooking experiment on calibrated beef roast, and to connect roast average cooking losses to the time-temperature profiles. Beef quality evaluation corresponding to these thermal data is presented in a second ICoMST 2009 communication [5]. Data will be discussed in the future using a combined modelling approach of heat-mass transfer and meat quality evolution.

II. MATERIALS AND METHODS

A. Materials

Beef samples were obtained from *Semimembranosus* (SM) and *Semitendinosus* (ST) muscles from 8 Friesian yearling heifers and 8 Friesian mature cows. The ST and SM muscles were cut into 4 samples each of 10x4x3cm and 15x5x3cm, respectively. Meat samples were vacuum packaged, frozen and stored at -20ºC until analysis. Before cooking, samples were thawed submerged in H_2O in a container with crushed ice overnight in a cooler (2±2°C). Thawed samples were placed in H_2O at 18°C during 45 min. for ST (10x4x3 cm) and 60 min. for SM (15x5x3 cm) to reach meat temperature of 18°C before starting microwave cooking.

B. Microwave cooking

Six or eight optical probes (FOT.L/1.5m; FISO Technologies Inc., Canada. Accuracy ± 0) were alternatively inserted in ST samples (10x4x3 cm) and SM samples (15x5x3 cm), respectively (Figure 1). Each sample was placed in a tray at the centre of a turntable domestic microwave oven with a frequency of 2.45 GHz. The microwave oven was provided with an electronic interface Microwave Workstation*TM* from FISO Technologies Inc.

Four treatments using combinations of power (250 vs. 900W) and temperature (60 vs. 80°C) were applied (2x2 factorial design): 250W60, 250W80, 900W60, 900W80. Microwave was stopped when the central deep probe (ST: B-D, SM: B-D and C-D, Figure 1) reached the target temperature (60 or 80°C). Probes were inserted before cooking with a difference of 10 mm between the superficial (10 mm from top surface) and deep probe (20 mm from top surface). After cooking the sample was placed on ice and cooled down until internal temperature reached 33°C. Each probe position was measured with a calliper after cooking.

C. Time-temperature profiles /Heating parameters

The time-temperature profiles were recorded during cooking for SM and ST from 8 heifers and 8 cows. The average time-temperature profile was calculated for 8 and 6 probe positions for SM and ST, respectively. In each roast three (ST) or four (SM) sections were considered including a superficial and deep probe and named from A (end that received MW first at the beginning of cooking) to C (opposite end of ST roast) or D (opposite end of SM roast) (Figure 1). The maximum temperature profile was calculated as the recordings from deep probes inserted in the end sections (ST: A-D and C-D, SM: A-D and D-D). The control temperature profile was considered from the probes inserted in deep central sections of each roast (ST: B-D, SM: C-D and B-D). The minimum temperature profile was considered from the probes inserted in superficial central section of each roast (B-S).

D. Cooking loss

Cooking loss was calculated by weight difference before and after cooking and expressed as g/mm^2 of exposed surface (all sides of the roast except the one in contact with the tray).

E. Statistical analysis

Data were analyzed as a factorial design with power (250 v. 900W), final internal temperature (60 vs. 80°C), animal age (yearling heifers and mature cows) and two- and three-way interactions in the model using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Sample raw weight was included as a covariate in the model.

III. RESULTS AND DISCUSSION

A. Time-temperature kinetics

Microwave heating have spatially heterogeneous effects that may cause hot- and cold-spots which compromise quality [6]. An heterogeneous cooked colour was observed in each roast indicating that a gradient of temperature was created within the roast during cooking mainly along the vertical cross section of the roast (perpendicular to muscle fibre direction). Underdone areas in the roast surface were observed being more evident in the central section (C, Figure 1), while the edges were overcooked or almost burnt especially at the bottom of the roast, which was in contact with the tray and meat juices generated during cooking. These results are in accordance with non-uniform microwave heating of cooked foods previously described by other authors [*2, 7*].

Figure 2 shows the time-temperature profiles during cooking (250W-80ºC and 900W-80ºC) for maximum, control and minimum temperature. The curves (maximum, control and minimum) for a cooking treatment (250W-80ºC or 900W-80ºC) showed that the temperature during the cooking process differed vertically from the top surface to the bottom and horizontally from the centre to the edges of the roast. The maximum temperature (above 90ºC) is reached at the deep edges of roast sections (ST: A-D+C-D, Figure 1), while the minimum temperature (about 60ºC) is reached at the surface centre section of the roast (ST: B-S, Figure 1). The control temperature, corresponding to probes inserted in the deep centre of the roast (ST: B-D, Figure 1) showed intermediate values between the maximum and the minimum temperatures (about 80ºC). Figure 2 also shows the effect of power on heating rate represented by the slope on the first part of the curve. Samples heated with high power (900W) showed a steeper slope indicating faster heating rate of the roast compared with the lower power (250W). The slopes of maximum, minimum and control time-temperature profiles were closer at 900W compared with 250W. Thus, temperature gradients created within the roast were lower when beef was cooked at 900W.

Table 1 shows the treatment times for ST and SM from heifers and cows for the different cooking treatments. Treatment times were on average greater for SM compared with ST muscle. This difference is in accordance with the rule that treatment time is roughly inversely proportional to the square root of the product size [8]. If the length of the product is chosen as its characteristic length, the theoretical ratio of the treatment times of the SM to the ST muscle should be about $\sqrt{15/10} \approx 1.22$, which is in accordance with the ratio of the average experimental times recorded for the two muscles (1192/1070 min. ≈1.11).

B. Cooking loss

Cooking loss is both due to water migration under the contraction of heated connective tissue and to the surface evaporation of water under free convection conditions. It is difficult to determine the respective effect of these phenomena, however in beef meat water migration due to contraction of connective tissue is a major factor of the cooking loss [9]. Table 2 shows the effect of age, power and temperature on cooking loss for ST and SM muscles from heifers and cows. There was no effect (P>0.05) of microwave power on cooking loss except for higher losses for 900 compared with 250W in SM from cows when cooked to 60°C. Power affects the treatment duration but not the level of inside product temperature. As there is no reason why surface evaporation should be affected by variations of the experimental conditions, cooking losses should increase with meat final temperature i.e. increase from 60°C to the 80°C treatment [9, 10]. This is the case for the ST muscle from young animals (80>60°C, numerically) and the SM muscle from mature animals (80>60°C, P<0.05). However, there are no differences in cooking loss between 60 and 80°C for ST from cows except for 900W, and for SM from heifers.

Results show differences in meat temperature and/or cooking loss between muscles from heifers and cows. For the ST muscle, recorded temperatures look on the average higher for cows than heifers (5-6°C difference in final temperature), while treatment time was on average 4% shorter for cows compared with heifers. No significant variation in cooking loss of ST is recorded between the young and old animals except for cows showing higher loss than heifers when cooked at 900W-60°C. For the SM muscle, temperatures recorded in beef from cows was also about 8°C higher than heifers and treatment times were significantly shorter (14% on the average) for cows than heifers. Cooking losses of SM roasts are significantly higher for heifer meat than for cow meat except for treatment 250W-80°C.

The fact that in some cases an increase of the final meat temperature does not lead to an increase of the cooking loss disagrees with literature. Similarly, differences in temperature and in cooking loss between cows and heifers cannot be explained by variations in meat thermal properties or meat structure. Meat thermal properties are not dependent on animal age but depend on water content, on fat content and on temperature [11]. Variation in thermal conductivity value due to fat or water content and to temperature ranges between 0.4 $Wm^{-1}K^{-1}$ and 0.6 $Wm^{-1}K^{-1}$ [11] which is not enough to explain the temperature variations observed in present results between cows and heifers. As difference in Warner-Bratzler measurements between young and old animals (not shown here) were not significant this does not plead for an effect of muscle structure on cooking losses. Moreover, if variations of structure should have affected the cooking loss between cows and heifers variation would be the opposite. Collagen content and collagen reticulation are greater for older animals. Thus, meat contraction and cooking loss under heating should have been greater for cows than for heifers which are the opposite of what it is observed here.

Discrepancy of present results with what can be expected from laboratory knowledge is probably connected to the difficulties in controlling the cooking process under practical conditions inside a deforming roast of meat subjected to important temperature gradients and juice migration. Initial difficulty to position the fibre sensors in raw meat and movement of sensors during cooking can lead to artificially greater or smaller temperatures for some treatments. If temperatures are artificially greater due to the positioning of the thermal sensor and especially of the sensor which control the treatment time, heating can be stopped earlier which will lead to a lower cooking loss than expected. This seems to have been the case for the SM muscle where treatment durations were significantly longer for heifers than for cows and were accompanied by greater cooking losses for heifers. Another explanation can be connected to the migration of cold or hot juice at specific locations which could have biased the determination of the actual average temperature of the sample. A detailed analysis of this problem requires the studying and the modelling of the juice migration inside the meat under the mechanical stresses generated by the thermal contraction of the connective tissues and of the muscle fibres. Such a work is in progress and presented in another paper of the congress [12].

IV. CONCLUSION

Microwave cooking of small roasts inside a domestic oven is heterogeneous whatever the chosen microwave power. Even when the raw shape and dimensions of the roast are known and well defined it is difficult to control the heating by positioning a temperature sensor at a given location inside the roast and stopping the treatment when a target temperature is reached. Classical thermocouple cannot be used during microwave heating and optical probes are difficult to position accurately inside raw meat. Moreover, probe location is moving during cooking due to meat contraction. Thus, similar controlled treatments could lead to significant variations of the temperature gradients inside the meat roast. This can affect the cooking losses which do not follow exactly what is expected from laboratory results obtained under more simple situations. During most studies on cooked meat sensorial or safety qualities, thermal treatment is simply controlled by locating a temperature sensor at the core of the sample and stopping the treatment at a target temperature. However, in complex situations temperature gradients shall be taken into account during the discussion on the evolution of product safety or sensorial quality.

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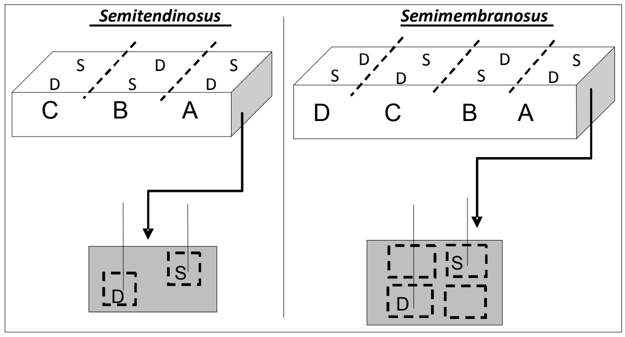

Figure 1. Diagram of probe position in ST and SM muscles. D: probes inserted in deep position (20 mm from top surface), S: probes inserted in superficial position (10 mm from top surface).

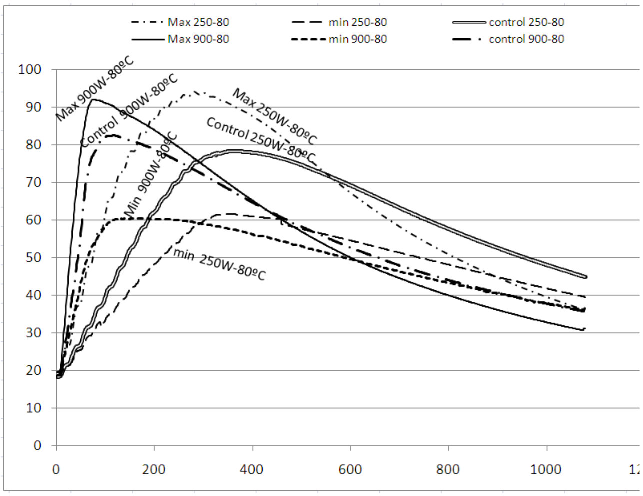

Figure 2. Time-temperature profiles during cooking at 250W-80ºC and 900W-80ºC for ST from heifers. The lines correspond to maximum (ST: A-D+C-D from Figure 1), control (ST: B-D from Figure 1), and minimum monitored temperatures (B-S).

Table 1. Time of treatment for ST and SM muscles from heifers and cows cooked with different power-temperature treatments.

			ST		SM	
Age	**Power**	**Temp**	**Time (s)**	**SE**	**Time (s)**	**SE**
Heifers	**250**	**60**	1094[b]	47	1258[c]	50
		80	1234[a]	47	1676[a]	48
	900	**60**	1026[b]	48	1235[c]	50
		80	1099[b]	47	1265[c]	49
Cows	**250**	**60**	1083[b]	47	1012[d]	48
		80	1146[ab]	47	1522[b]	50
	900	**60**	979[c]	47	1112[cd]	50
		80	899[d]	48	1252[c]	48

Means within the same column with different letters differ (*P* < 0.05).

Table 2. Cooking loss (g/mm^2, lsmeans±SE) for ST and SM from heifers and cows with different power-temperature treatments.

Age	**Power**	**Temp**	**ST**	**SM**
Heifers	**250**	**60**	1.7E-03[c] ±3.2E-04	4.9E-03[a] ±2.7E-04
		80	2.3E-03[bc]±3.2E-04	4.4E-03[ab] ±2.4E-04
	900	**60**	1.9E-03[c] ±3.2E-04	4.9E-03[a] ±2.6E-04
		80	2.6E-03[abc] ±3.2E-04	4.7E-03[a] ±2.5E-04
Cows	**250**	**60**	2.6E-03[abc] ±3.2E-04	1.9E-03[d] ±2.4E-04
		80	2.9E-03[ab] ±3.2E-04	4.0E-03[b] ±2.6E-04
	900	**60**	3.5E-03[a] ±3.2E-04	2.9E-03[c] ±2.5E-04
		80	2.6E-03[bc] ±3.2E-04	3.8E-03[b] ±2.5E-04

Means within the same column with different letters differ (*P* < 0.05).